NISTIR 6890

# Fire Resistance Determination and Performance Prediction Research Needs Workshop: Proceedings

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## HISTORY AND CURRENT PRACTICE

**P. DiNenno and C. Beyler**

DiNenno and Beyler (Appendix III. C) provided an overview of designing fire resistance for buildings. The first fire endurance tests in the U.S. were conducted in Denver on floors in 1890. The New York City Building Department adopted a code around 1900, which required floor systems to endure a five hour exposure to a furnace maintained at a temperature of 1100 °C with a mass loading of 211 kg/m$^2$, and to subsequently withstand a load four times this for 24 h. A furnace for conducting the test was located at Columbia University. The Baltimore fire in 1904 led to the formation of an ASTM committee to develop an American standard for fire resistance. The first standards were released in 1908, with similar load requirements but the peak furnace temperature decreased from the New York code to 927 °C. Within the next ten years, testing was being conducted at Factory Mutual, the National Board of Fire Underwriters, the National Bureau of Standards and Underwriters Laboratories. Standard fire resistance tests for loaded columns began to be developed at UL around 1917. The year 1918 saw the release of ASTM C19, the first edition of the standard that is now numbered ASTM E119 [1], which contained provisions for floor and wall testing using a standard time-temperature curve and a 25% safety factor with respect to time. Ingberg [2] of the National Bureau of Standards led the efforts in the U.S. during the 1920s, examining different fuel loads and suggesting that integrating the furnace temperature over time was a way to compare performance among various fire scenarios and furnace conditions.

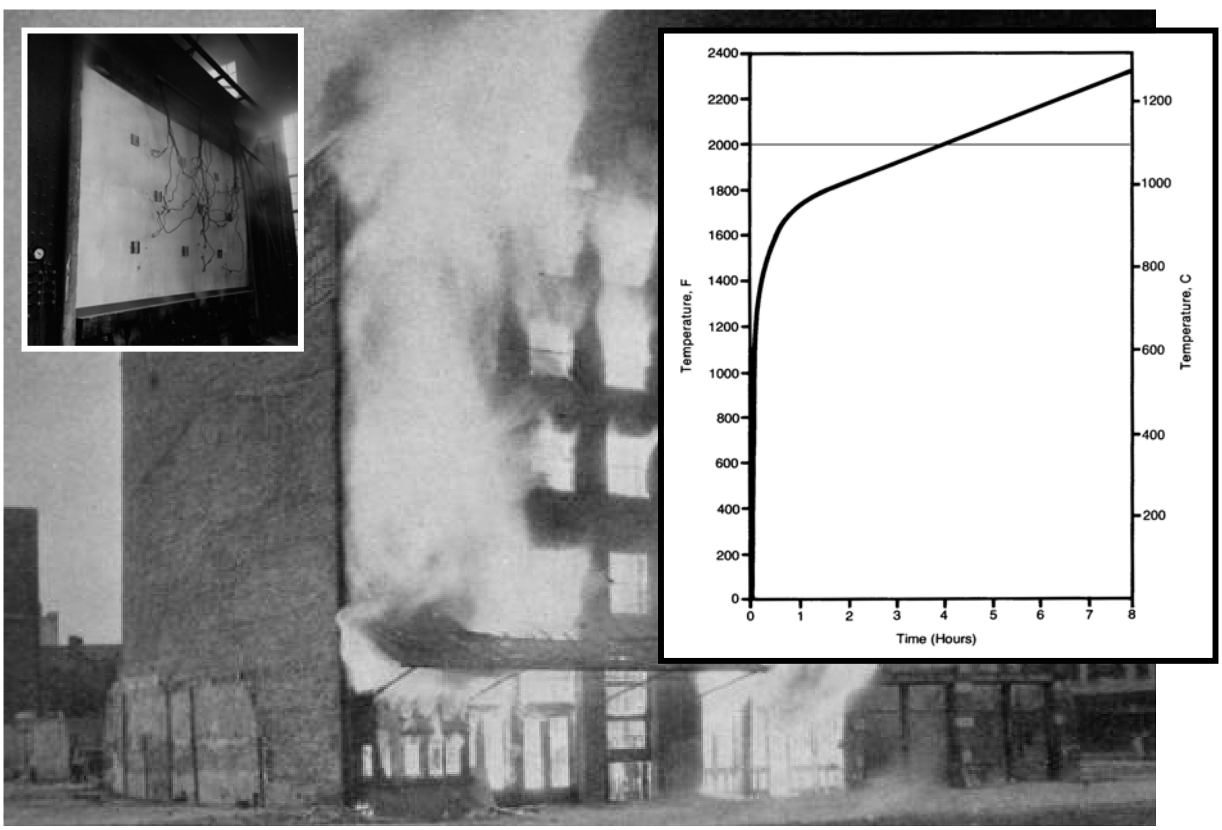


Figure 1. Photograph [3] of building fire as part of a series of tests used to develop time-temperature curve. Inset is a wall assembly ready for testing in the ASTM E119 furnace.

The compelling needs for fire resistance are the following:

- to prevent building collapse;
- to prevent fire spread from building to building;
- to contain the fire from spreading horizontally through wall partitions and vertically through floor assemblies;
- to maintain safe means of egress;
- to control the movement of smoke; and
- to provide for fire fighter safety

Today, fire resistance requirements are established in a purely prescriptive manner by building code and are a function of occupancy, height and area of the space, and whether or not sprinklers are present. Testing is done routinely at many commercial laboratories following the procedures specified in ASTM E119, NFPA 251 [4], ISO 834 [5], or some variant developed by FM or UL. A standard time-temperature curve, based upon the work of Ingberg, is used to challenge the test specimen. Pass/fail criteria are based upon the peak temperature attained at the back of the test article and/or whether or not the test article collapses or distorts in a fashion that allows hot gases to escape (and in the case of E119, whether the wall can withstand the pressure of a hose stream). Many structural elements are tested unloaded; there is no limit on the amount of deflection that a beam can undergo and still pass the test; and connections are not tested at all. Products that are tested with these methods are assigned an equivalent fire endurance time (in hours).

The materials and systems currently used to provide fire resistance to structural members include sprayed fibers, cementitious materials, mastics, intumescent paints, suspended ceilings and drywall assemblies (membranes), concrete encasements, tiles, and plaster/lath. The adhesion and cohesion properties of spray-on fireproofing [6], and gross behavior when exposed to modest deflection and indirect impact loads are measured in standard tests [15, 16], but hardness and resistance to direct impact are not explicitly measured.

While a number of revisions were made to the above standards throughout the twentieth century, the prescriptive nature for these fire resistance test methods remains unaltered, in spite of changing fire loads and significant advances in our knowledge of fire and structural behavior. As early as the 1950s the engineering community was beginning to understand a number of situations that caused the fire exposure curve established by Ingberg [2] to vary significantly from reality, including post-flashover fires, ventilation controlled fires, and different insulation properties of wall linings. More was understood about the thermal response of columns and beams to changes in temperature, with new analytical, numerical, and experimental methods being developed to predict column buckling, beam deflection and truss deflection. Finite element heat transfer models, structural response models (e.g., FASBUS [7]), and models of post flashover fire conditions (e.g., COMPF [8]) were available by 1980. It is suggested by DiNenno and Beyler (Appendix III. C) that all of these tools can be brought to bear on the problem of predicting fire resistance performance of structural systems.

Figure 2 provides a framework for working these issues. Design fire exposure should be dictated by a modern fire load survey, and the knowledge gained from our capability to characterize local heat flux in a way more meaningful than provided by the well-stirred assumption. Data on the thermal and mechanical response of insulation systems needs to be institutionalized, and standard test methods and performance criteria developed for mechanical response, non-fire impact loading and fire exposure. The performance of fire barriers is needed along with that of load-bearing elements. The relative role for full structural models and detailed local deformation analysis needs to be assessed, especially regarding the performance of connections. A full compliment of test methods are needed to establish engineering properties. Furnace testing should be severe; e.g., ASTM E1529 [9] is a simple bounding fire exposure that provides a harsher (compared to ASTM E119) thermal test of the mechanical properties of fireproofing materials. Test methods should relate more directly to the mechanical and thermal environment likely to be experienced in a real structural fire, and should be used primarily as a validation of engineering methods. Performance criteria must be established depending upon the question being asked.

The greatest difficulty encountered in advancing fire resistance performance prediction, according to DiNenno and Beyler, is translating our increased understanding and technology into codes and standards. It is necessary to develop a broad consensus for the need to change how fire protection engineering is done. Science-based fire protection design practices need to be codified, and building codes must be formulated to accept new practices. Education of engineers, architects and authorities having jurisdiction is essential. Science-based structural fire protection is technically achievable, though it will require a total reexamination of how things are done, from product listing to design to operations (inspection, testing and maintenance). The payoff is known cost-effective performance and assured safety.

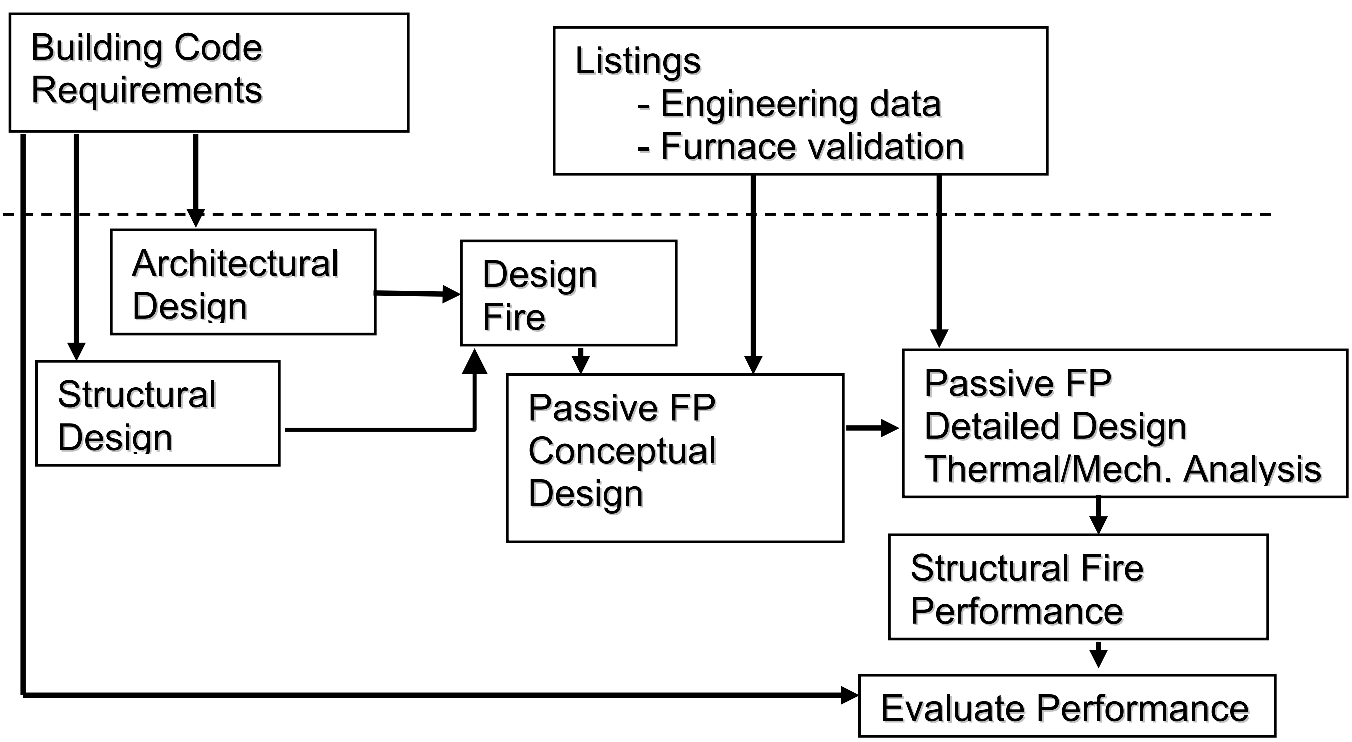


Figure 2. Science-Based Structural Fire Protection Design (DiNenno and Beyler)

**J. Milke**

Milke (Appendix III. D) described an effort by the American Society of Civil Engineers (ASCE) and the Society of Fire Protection Engineers (SFPE) to develop a standard on performance-based structural fire protection analyses, motivated by the difficulty in relating the current comparative tests to actual fire performance. The new standard will outline calculation procedures to link the results of tests to structural performance. Other organizations involved in the effort include the American Iron and Steel Institute (AISI), the concrete industry, the Masonry Alliance for Codes and Standards, and the American Forest and Paper Association (AFPA). The analytical framework is shown in Fig. 3. The material properties, thermal response and structural response of concrete, masonry and steel are each handled in their own section of the standard. A role will exist for simple calculations, advanced computations and experiments, all working together to determine the performance of individual structural elements, structural assemblies, and the global response of the building.

The fire exposure will be based upon heat flux (including radiative and convective contributions) as a function of time as well as temperature vs. time. Pool fires, distributed fires, and external fire exposures will be included. The thermal response of the structural elements can be followed using multi-dimensional finite element analysis with the boundary conditions provided by the (experimental and/or numerical) fire exposure. Although some material properties have been tabulated, many more, especially at higher temperature, have to be compiled. The structural response will be determined by a combination of first-order, single element analyseis (column stability, moment analysis of a slab/beam, isothermal over a range of temperatures). Computer simulations are needed to account for temperature distributions in space, variable cross-section members, complex loading, and frame analyses. Additional experimental programs are required to develop a complete material properties data base, to better characterize complex material behavior (cracking, adherence, charring and spalling), to calibrate models, and to examine interactions between component building assemblies and adjacent building assemblies within the larger structural frame.

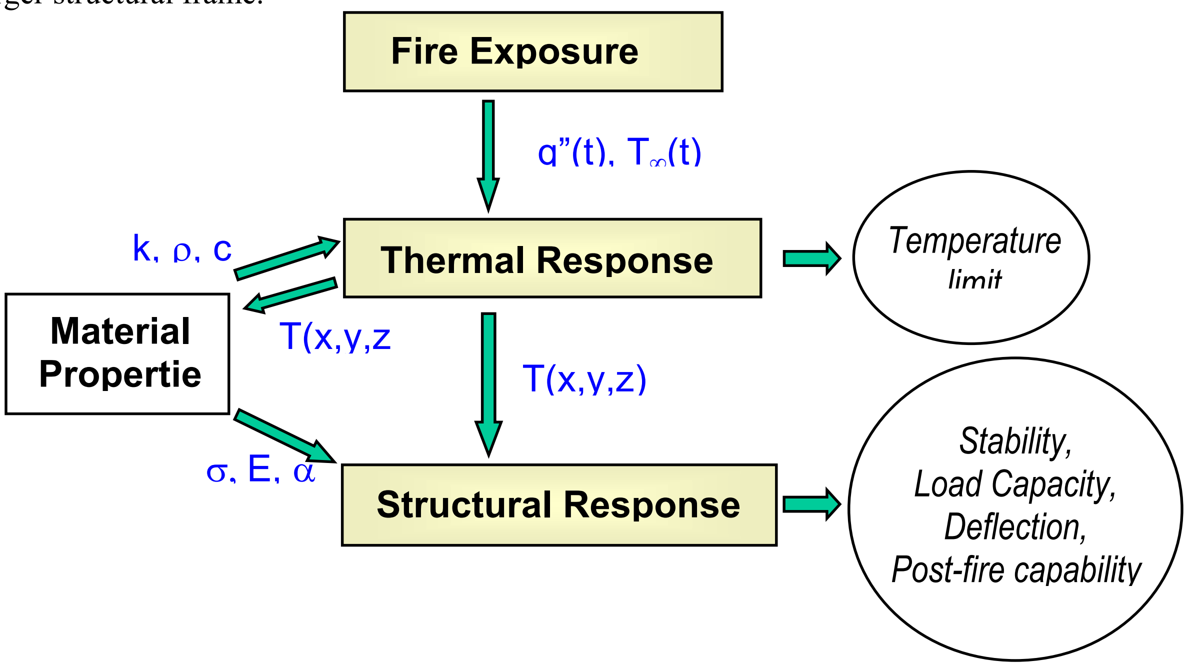


Figure 3. Analytical framework for ASCE/SFPE pre-standard (Milke)